HQ Air Force Center for Environmental Excellence (AFCEE)

Integrity - Service - Excellence

Groundwater Circulation Well Technology Review

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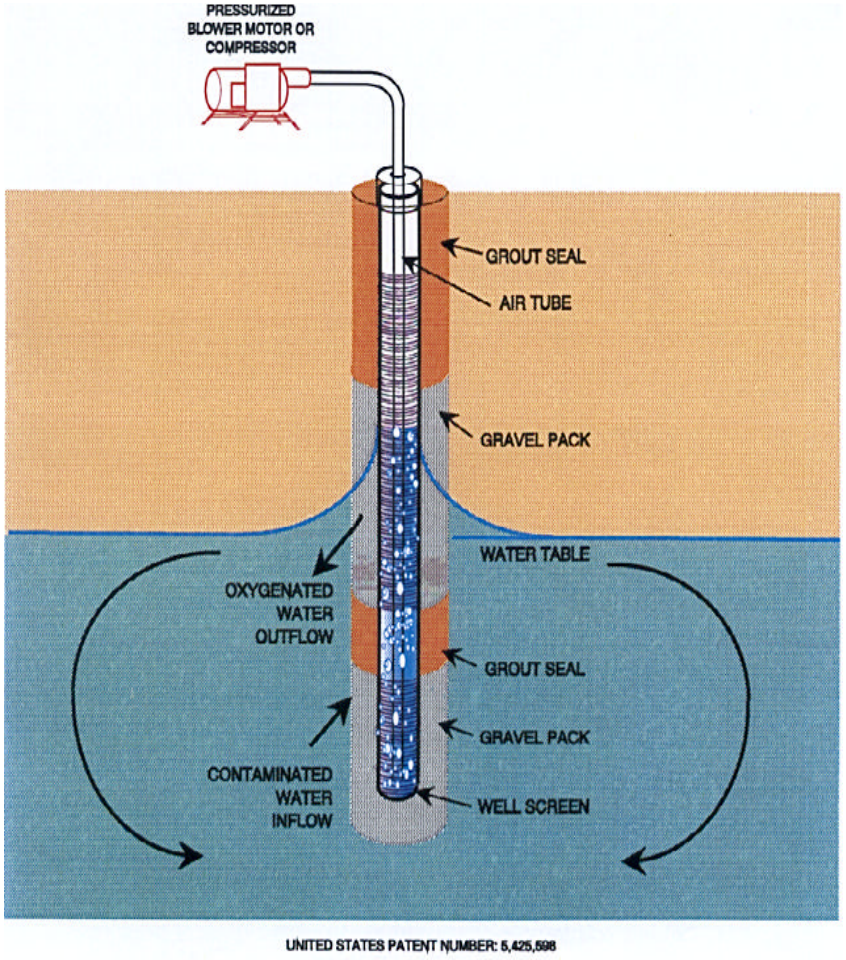
GCW BASICS

- **Also Called Recirculation Wells, UVB, NoVOCs, Density Driven Convection, etc.**
- **Groundwater is Extracted From One Depth, Treated in Well, Usually Aerated, and Discharged to a Different Depth**



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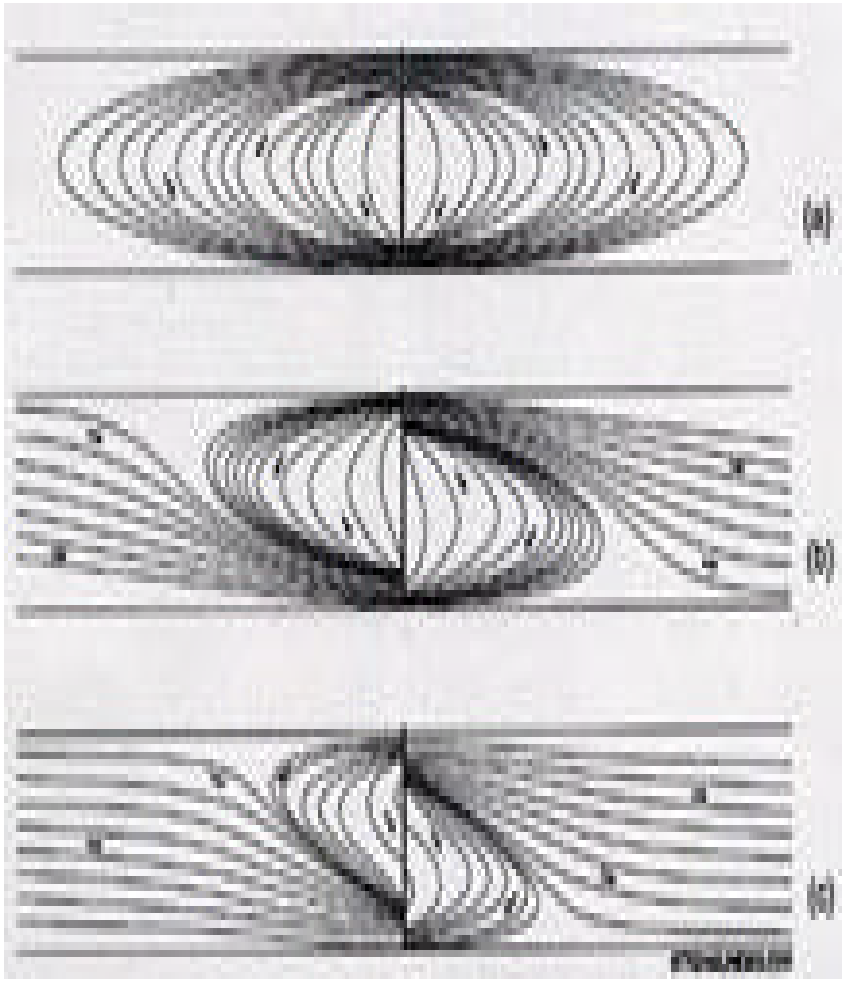
GCW - BASICS

- Objective is to develop "Recirculation Cell" in the aquifer
- Generally, relies on multiple passes through GCW in order to achieve "significant" reductions in concentrations



GCW - Demonstration Sites

- Cape Canaveral AFS
- Edwards AFB
- Hill AFB
- Keesler AFB
- March AFB
- Massachusetts Military Reservation (MMR)
- North Island NAS
- Oceana NAS
- Port Hueneme
- Tyndall AFB
- Yuma MCAS
- Others

AFCEE Position on GCW Technology

- **Special case of Extraction, Treatment and Re-injection (ETR):**
  - **single well used for extraction and re-injection**
  - **treatment occurs down hole versus aboveground**
- **GCW is not a wholly different process**
  - **simply depends on chosen point of re-injection**
  - **ETR systems can be designed in *close-coupled configuration* with traits similar to GCW**

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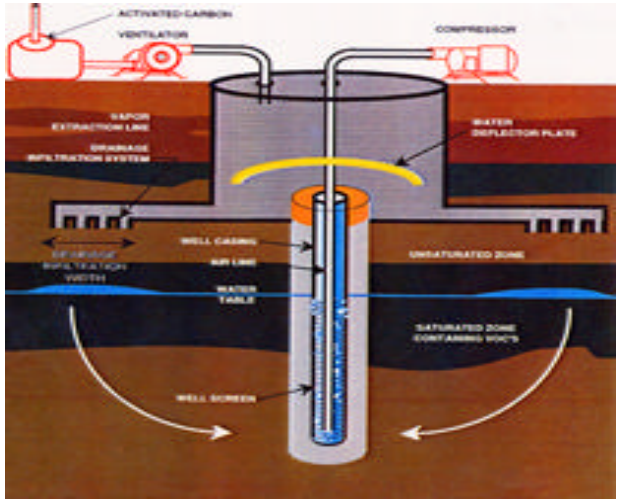
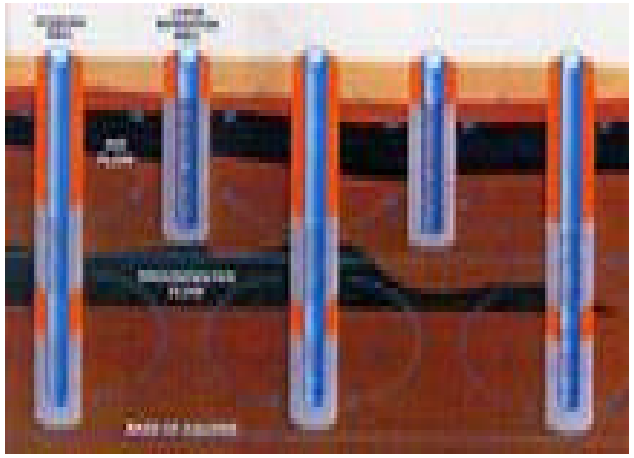
Close-Coupled Configuration

- Refers to ETR systems designed with re-injection wells very close to the extraction wells
  - extraction and injection screens adjacent to each other at same depth intervals as GCW
  - such a system would operate much like GCW
  - avoiding, however, many shortcomings of traditional GCW technology





Extraction-Treatment-Reinjection Continuum

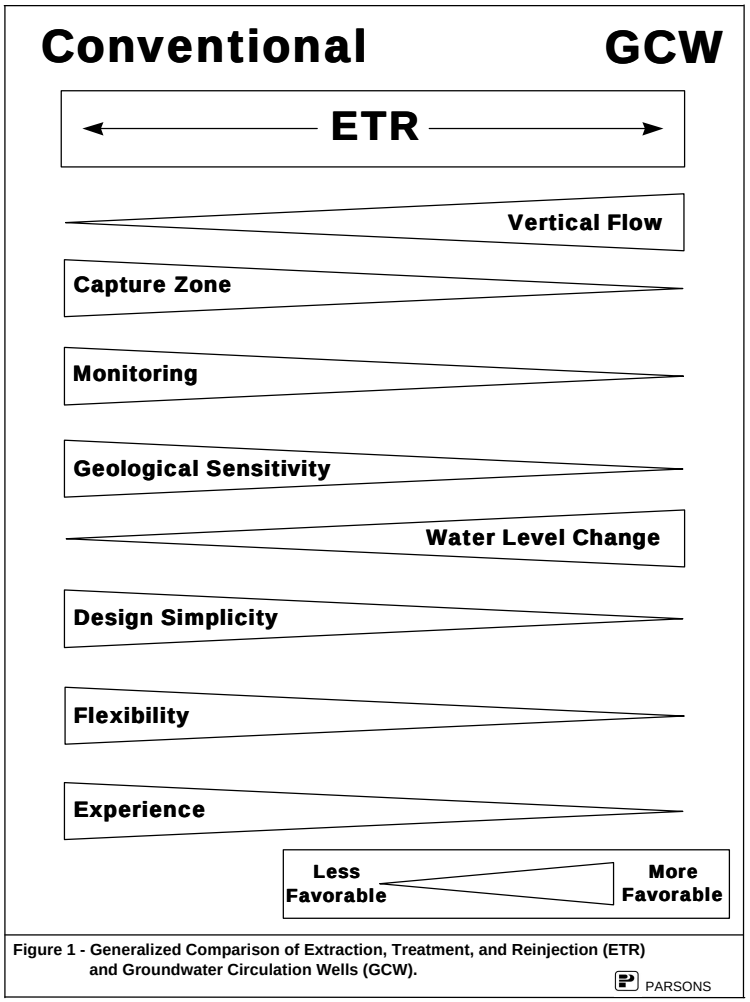


Figure 1 - Generalized Comparison of Extraction, Treatment, and Reinjection (ETR) and Groundwater Circulation Wells (GCW).

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GCW - Vendor Claims

CLAIMS:	AFCEE EXPERIENCE:
More Effective Than Pump and Treat (PnT)	Not substantiated
Lower Cost Than PnT	Not substantiated
Fewer Wells Than PnT	Not substantiated
Lower Energy Requirements Than PnT	NO!
All Components Below Ground	Yes, but …
Permitting Advantages Over PnT	Yes, but ...

GCW - More Effective Than Pump and Treat?

- Vertical flow has potential to increase removal of NAPL
  - However, if no highly contaminated source zone exists, then no value in inducing vertical flow
- Radius of Influence is generally less (at given flow rate)
  - Portion of effluent is recirculated
    - Represents previously treated Groundwater
  - Volume Limited with respect to first pass fraction
- Recirculation promotes dilution (less efficient)
  - Mass Flux (mg/min) = Flow rate (L/min) X Conc. (mg/L)
  - Mass Loading Limited due to recirculation
- Difficult to Assess Advantages Accurately
  - Usually Based on Modeling or Indirect Evidence

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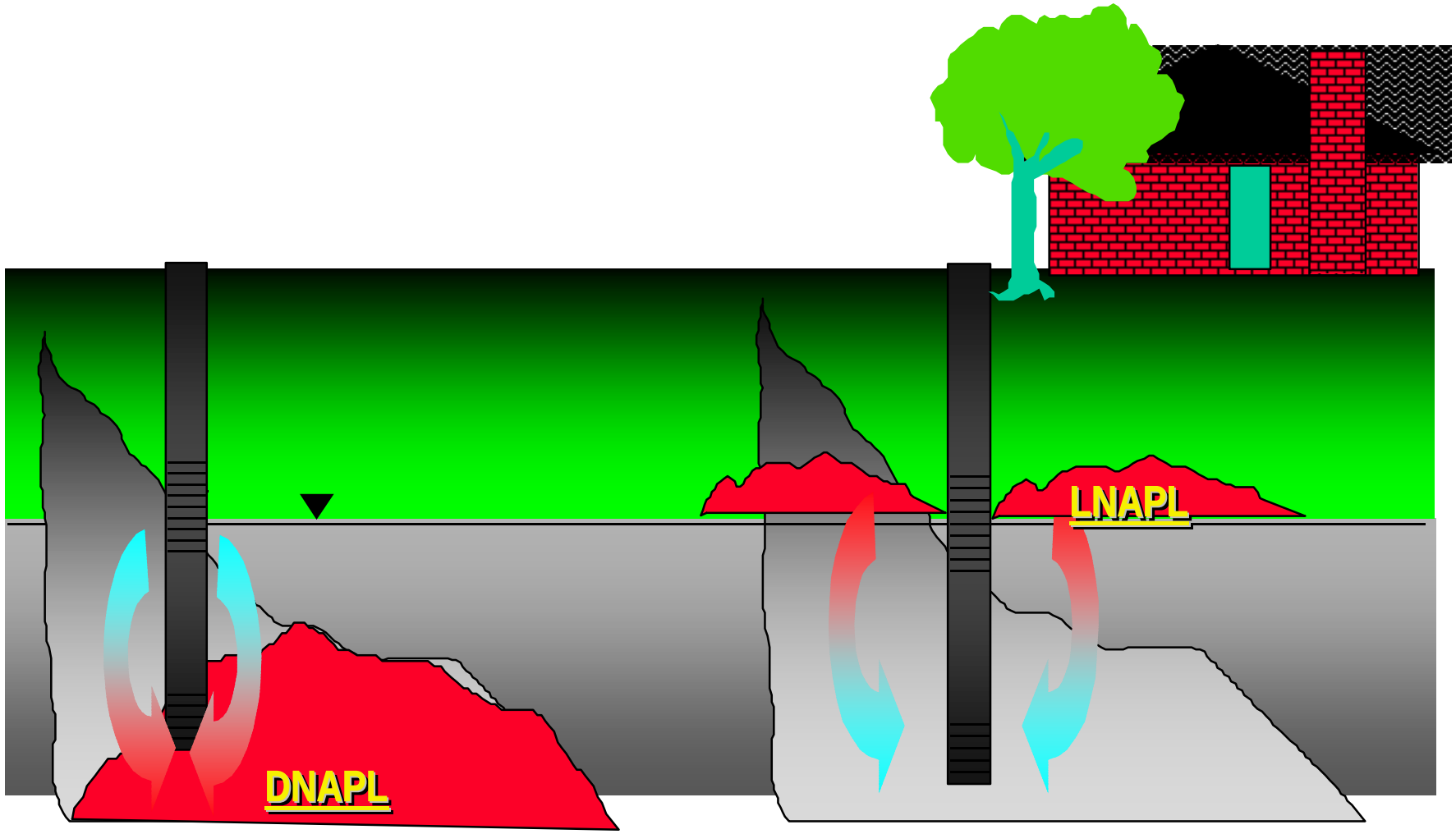
GCW - Vertical Flow Advantage with NAPLS



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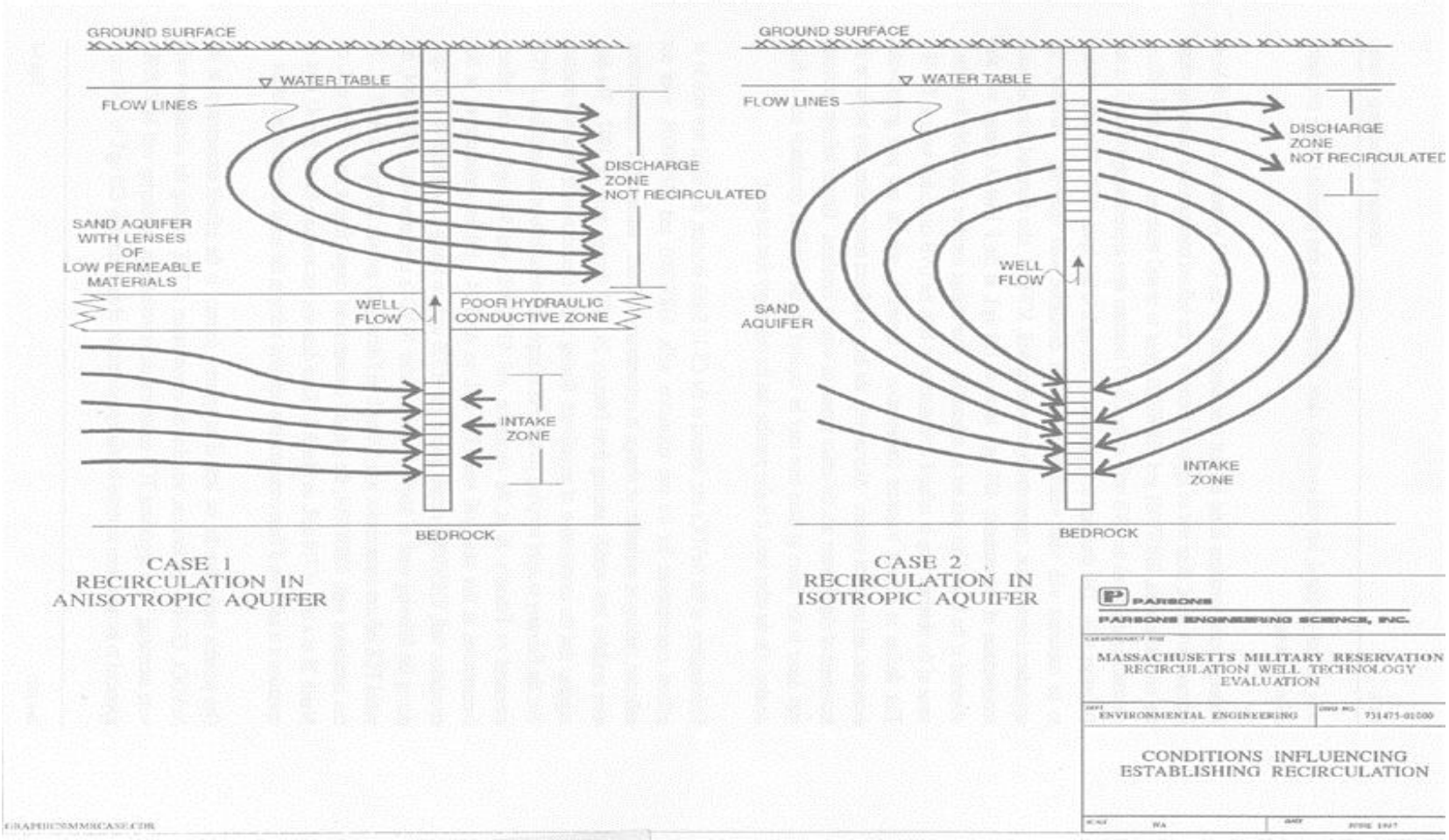
GCW - NAPL Dissolution

Without Capture = Mobilization



GCW - NAPL Mobilization at Keesler AFB MS

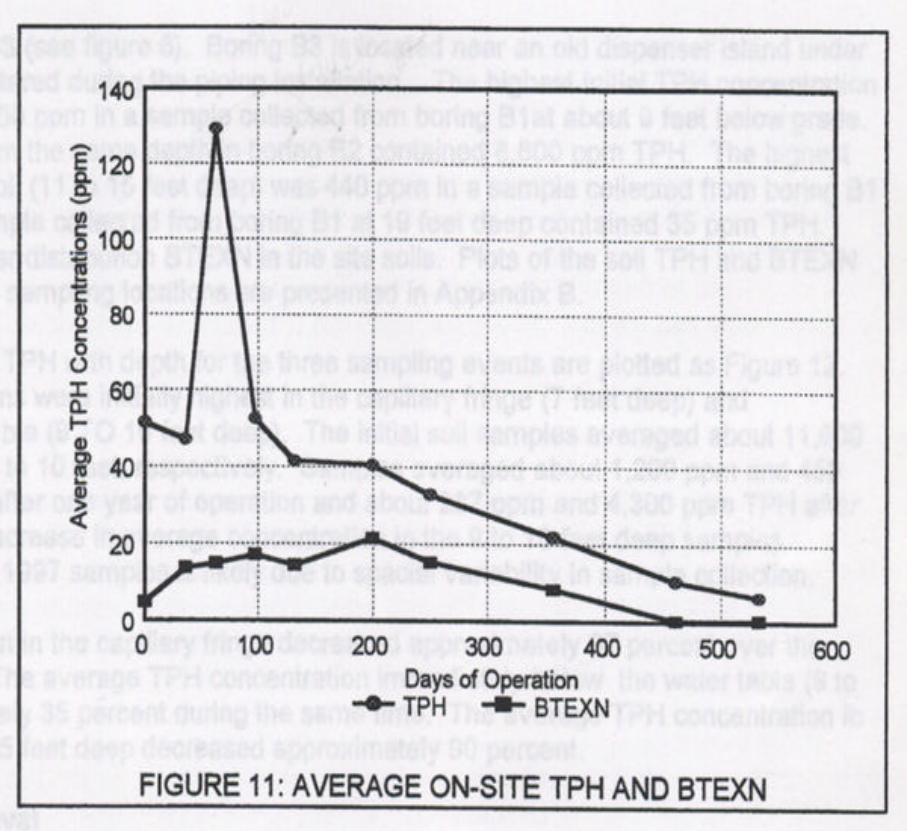


FIGURE 11: AVERAGE ON-SITE TPH AND BTEXN

Source Area Concentrations

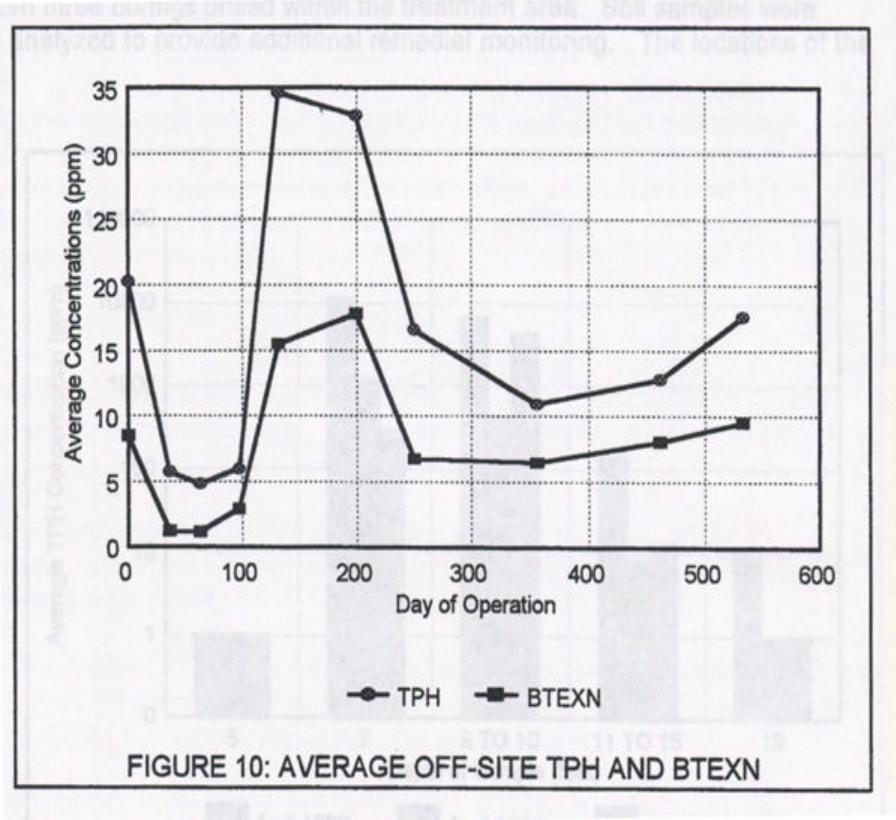


FIGURE 10: AVERAGE OFF-SITE TPH AND BTEXN

Down Gradient Concentrations

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GCW - Lower Cost Than Pump and Treat?

- Little Direct Field Evidence
- Cost of Monitoring GCW>PnT
  - Complexity
- Cost of Engineering GCW>PnT
  - Limited vendors
- Cost of O&M GCW>PnT
  - Down-hole
- Permitting costs GCW<<PnT
- Energy (Pumping Cost)?
- Number of Wells?

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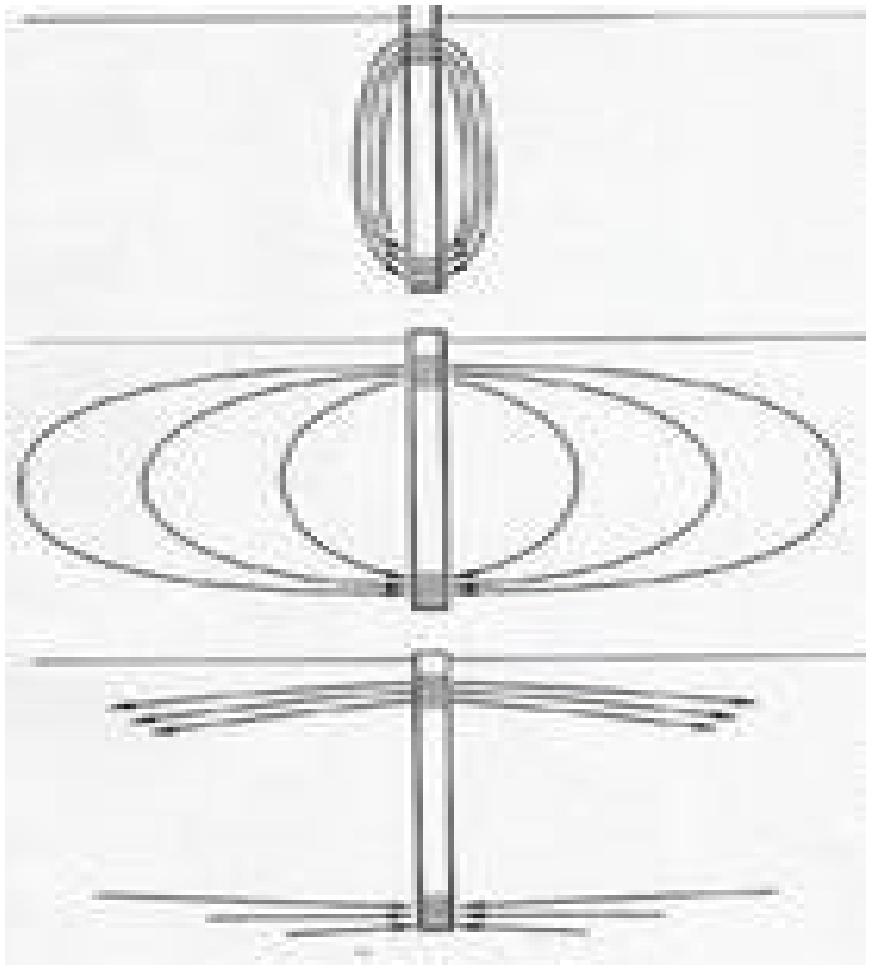
GCW - Fewer Wells Than Pump and Treat?

- GCW Single Well
  - Extraction & injection in same well
  - However, GC Well is More Expensive
    - More complex
    - Down-hole components
    - Larger diameter
    - Multiple screens
- Radius of Influence of GCW<PnT (at given flow rate)
  - Volume limited due to Recirculation
  - Mass Loading limited due to Recirculation
- Therefore, additional wells may be required

GCW - Radius of Influence



- GCW circulation geometry is effected by anisotropy
  - Anisotropy is basically the ratio of Kh:Kv
- Short Circuiting Condition
  - Kh:Kv = 0 to 3
  - Ratio too low
- Ideal Conditions
  - Kh:Kv = 3 to 10
  - Optimum Ratio
- No Circulation Condition
  - Kh:Kv = >10
  - Ratio too high

GCW - Lower Energy Requirements Than Pump and Treat?

- **Energy costs are proportional to height to which water must be lifted for treatment**
  - **However, Hill AFB study indicated GCW at 100 ft. would require more energy than PnT**
- **More Air is Required for Co-current Stripper**
  - **Most Air Strippers use Counter-Current Flow**
    - **Air and liquid flow in opposite directions**
    - **More efficient, requiring a lower Air:Water ratio**
    - **99.9% efficiency air strippers widely available**
  - **Most GCW systems use Co-current Flow**
    - **Air and liquid flow in the same direction**
    - **Less efficient, requiring a higher Air:Water ratio**
    - **70-93% operational stripping efficiencies generally seen**

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GCW - All Components Below Ground?

- **Not Always**
  - **Carbon Canisters for off-gas capture**
  - **Down-Hole Carbon Canisters have been discussed**
- **Also Possible with Pump and Treat**
  - **Air Stripper could be placed in vault - if you wanted**

GCW - Permitting Advantages Over Pump and Treat?

- **YES - No Question!**
  - **“As long as groundwater is not brought to surface …”**
  - **No re-injection issues**
  - **But EPA is taking notice**
  - **Things may change**

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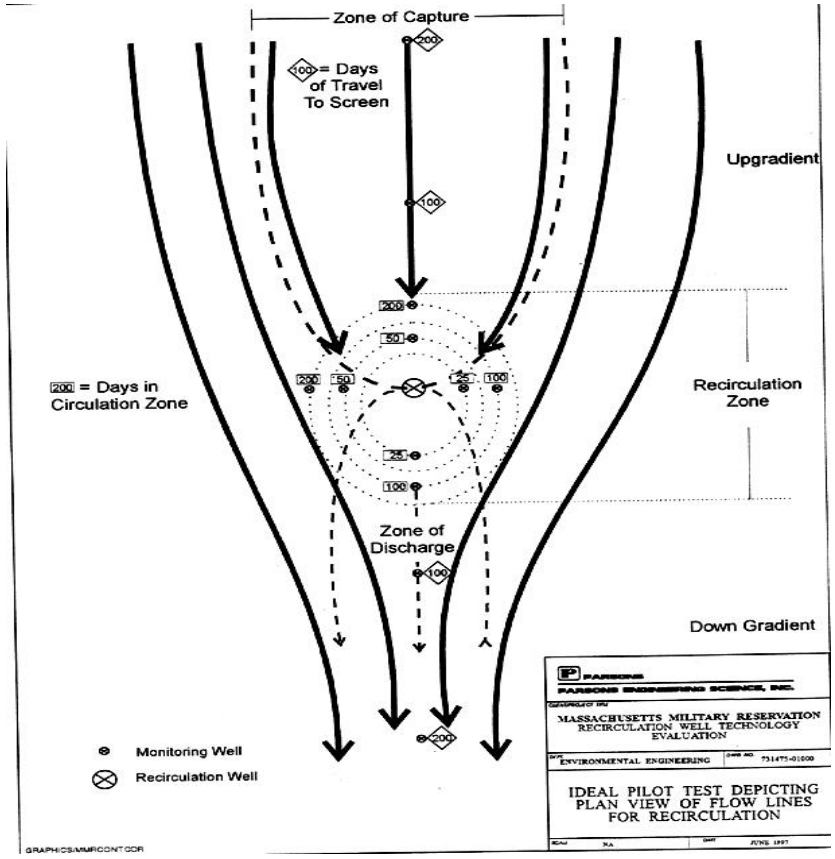
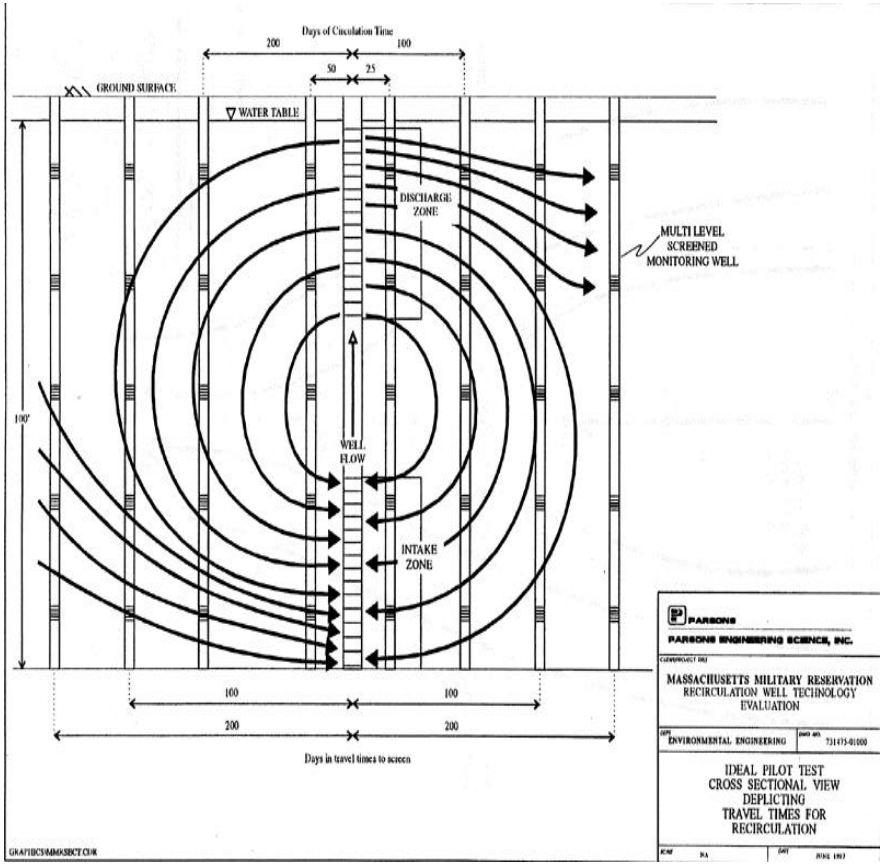
Other Issues: Monitoring Considerations

PLAN VIEW



CROSS SECTION



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Other Issues: Monitoring Considerations

- Monitoring is more difficult than PnT
- Recirculation Cell is very difficult to prove or quantify
  - Zone of Influence is 3-Dimensionally, Heterogeneous
  - Requires extensive tracer studies
  - Often relies on pressure transducers, changes in gradient heads, and extensive modeling
- GCW process monitoring is difficult
  - Geochemical changes within aquifer
  - Mass balances difficult to calculate
    - Degree of Recirculation
    - Inaccurate flow rate measurements
    - Mass = Concentration X Flow rate
- Therefore, monitoring optimization maybe more difficult

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Other Issues: O&M Considerations

- O&M is more difficult - <u>Everything is down-hole</u>
  - Assume Reliability(i.e., Mean-Time-Between-Failure) for PnT and GCW is equal,
  - Maintainability (Mean-Time-to-Repair) has to be greater due to down-hole nature of GCW
- Injection Well Plugging is more problematic
  - Iron
  - Carbonate
  - Biofouling
- Effluent screen & well replacement: GCW vs PnT
- Process Optimization may be more difficult due to operational and design limitations of GCW system

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"What we got here is a failure to recirculate … "

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GCW - an Emerging Technology?

- 10+ year old technology
- Not well understood or documented
- No widespread commercial acceptance
- Potential value for NAPL treatment unproven
  - Keesler AFB
  - Cape Canaveral AFS

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GCW - Reasons to Use

- Vertical Flow for Improved NAPL Treatment
- Severe Permitting Problems
- A placebo needed

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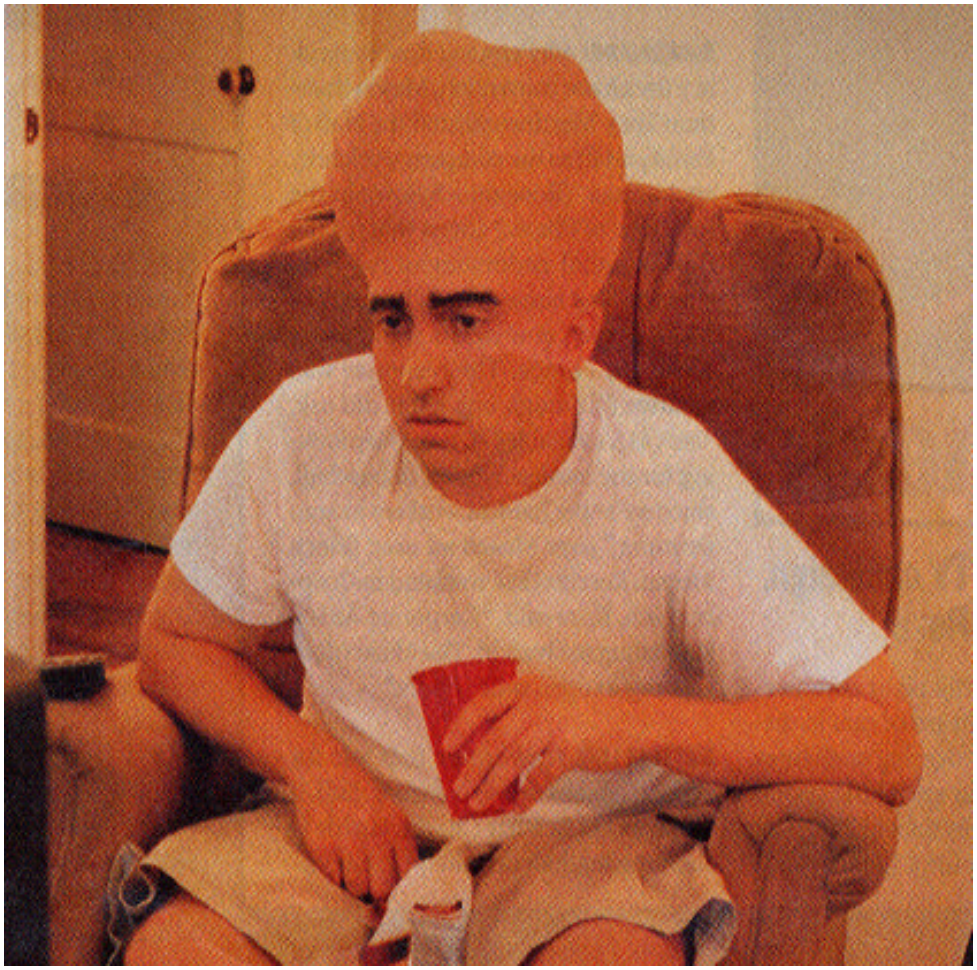
Conclusion

- There are good reasons for promoting the use of emerging or innovative technologies
  - When potential to either be more effective, or less costly than conventional technology there is logic in taking risk
- Unfortunately, no widespread potential for GCW to be either more effective or less costly than ETR

GCW Technology - It's A Lot to Absorb



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Backup Slides

Extraction-Treatment-Reinjection Continuum

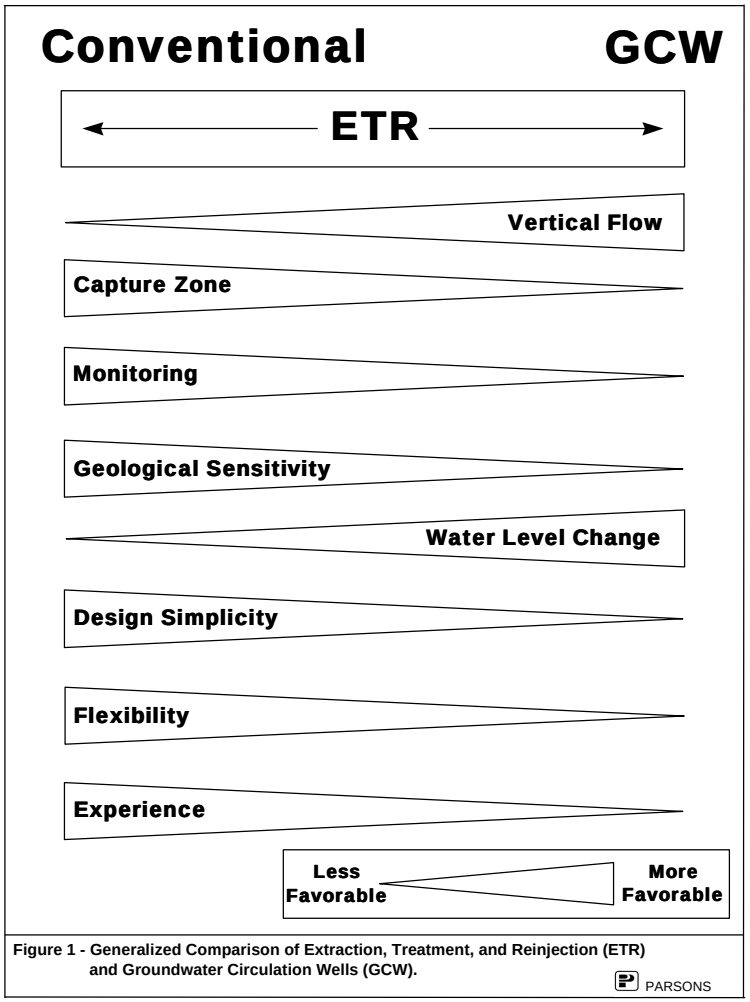

Figure 1 - Generalized Comparison of Extraction, Treatment, and Reinjection (ETR) and Groundwater Circulation Wells (GCW).

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Vertical Flow

- Vertical flow has potential to increase removal of NAPL/sorbed material
  - however, if no highly contaminated source zone or sorbed material exists, then no value in inducing vertical flow as with GCW Sub-bullet two
- Greater process treatment efficiency obtained with improved treatment aboveground in an ETR system
  - again, if greater efficiency aboveground, then no value in inducing vertical flow as with GCW
  - however, energy costs of pumping water is proportional to height to which water must be lifted for treatment

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Capture Zone

- For purpose of plume capture it is not necessary to create a circulation cell
  - however, failure of GCW to create a circulation cell could result in limited or no plume capture
  - lack of circulation cell development could spread contaminants into previously uncontaminated areas
    - poor in-well treatment efficiency followed by re-injection
    - dissolution of sorbed material escaping down gradient Major bullet two
- Circulation cell reduces volume of untreated groundwater capable of being captured and treated
- Complicated by non-uniform capture zones with depth

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Monitoring Considerations

- GCW & close-coupled ETR expected to be more difficult, extensive & costly than conventional ETR
  - groundwater flow in capture zone of conventional ETR relatively simple to determine with reasonable certainty
  - GCW and close-coupled ETR requires monitoring with respect to depth and distance of 1) hydrostatic pressures and 2) vertical & horizontal permeability's
  - interpreting groundwater quality data with respect to depth and distance is also challenging
  - complexity common for both site characterization and operational monitoring

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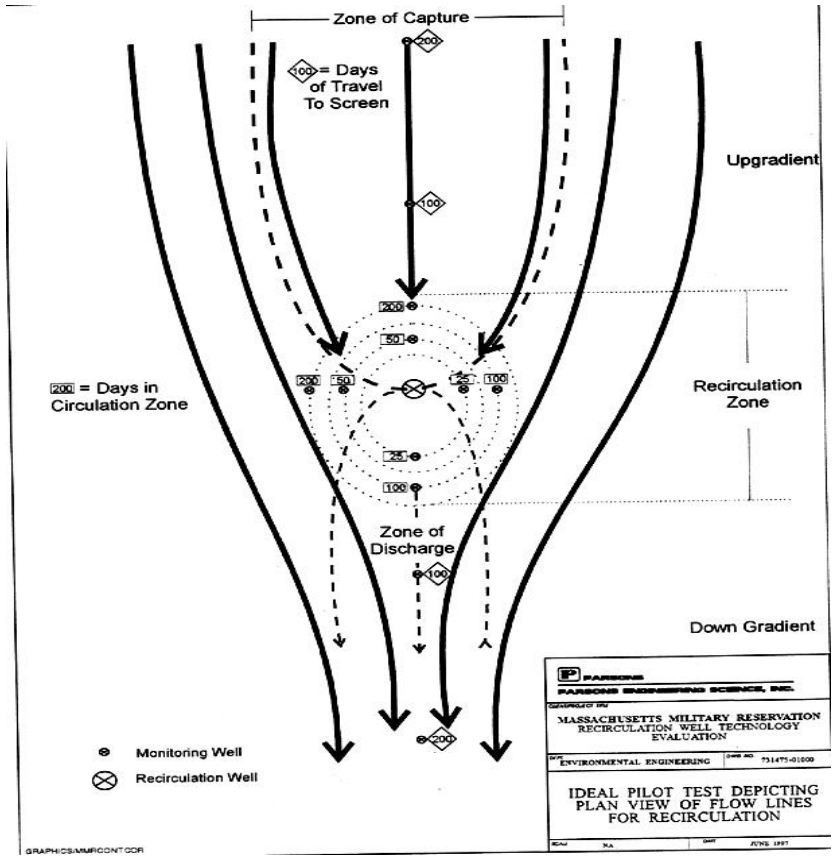
GCW Monitoring

PLAN VIEW



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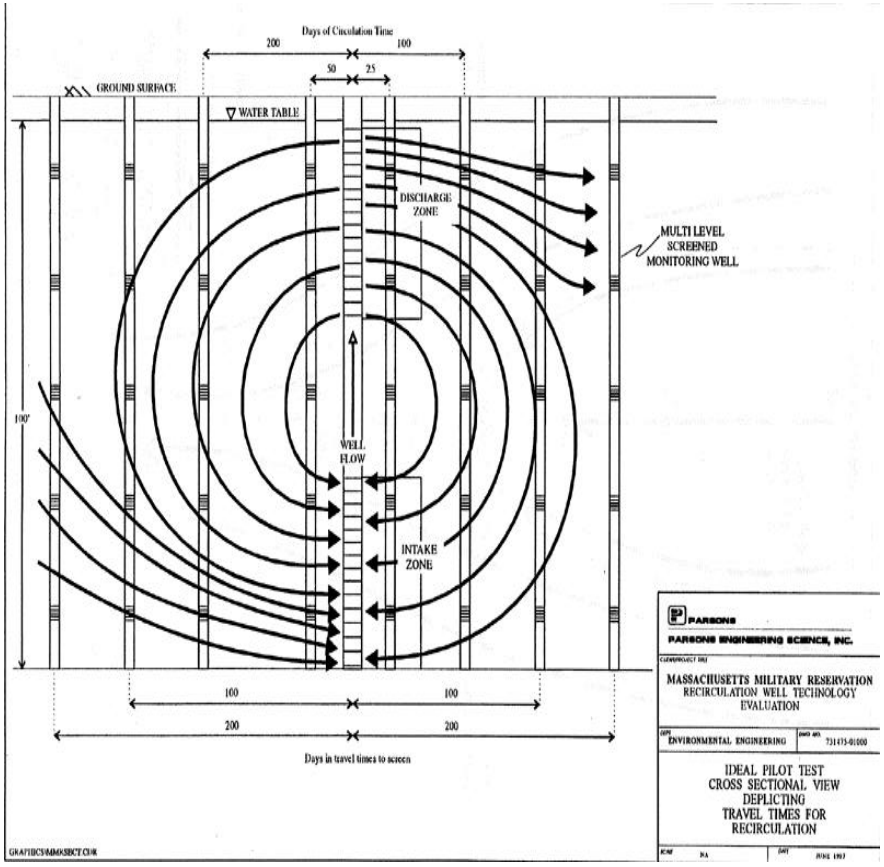

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Geological Sensitivity

- GCW & close-coupled ETR more sensitive to geological and hydrogeological conditions than conventional ETR
  - impact of stratification on vertical permeability
  - single thin stratum of lower permeability can have significant impact on vertical permeability
  - Example
    - 100•ft thick homogenous sand where Kh=Kv=0.01 cm/sec; ratio=1
    - Introduce 1•ft clay layer where K=0.000001 cm/sec
    - average Kh decline by 1%; however, Kv declines by 99%
    - groundwater escapes down gradient as no cell develops

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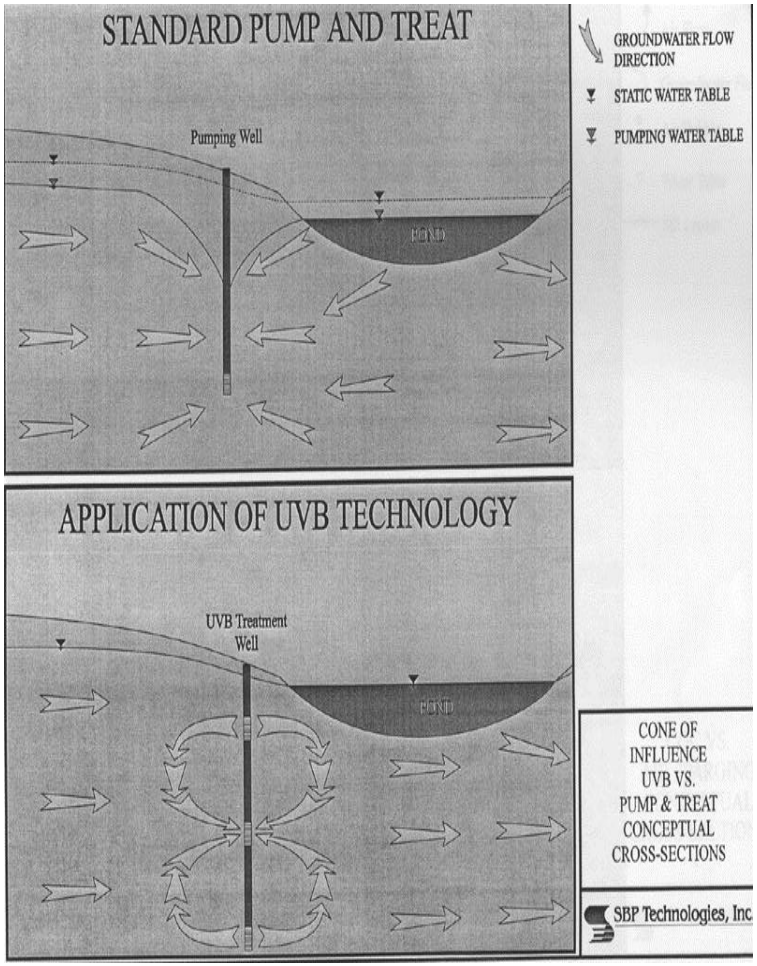
Water Table Impact



- A potential concern at sites
- GCW designed to operate with minimum impact
- However, ETR design possible with no more or less adverse impact than GCW or close-coupled ETR
  - requires placement of injection wells in locations that would provide the desired control in critical locations

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Simplicity of Design

- **ETR**
  - **conventional well**
  - extraction & injection wells
  - **single screen**
  - **single pump (extraction)**
  - **equipment aboveground**
  - **typically smaller diameter**
  - **less soil cuttings**
  - **typically less costly to install**
  - **almost all use counter-current air strippers**
- **GCW**
  - specialized wells
  - **extract/re-inject same well**
  - 2 or more screens
  - multiple pumps possible
  - more equipment down-hole
  - larger in diameter
  - more soil cuttings
  - typically more costly to install
  - most use co-current air strippers

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Design Flexibility

- **ETR**
  - Uses separate extraction and injection wells
  - **Individual well flow possible**
  - **Optimize extraction rate**
  - Modify groundwater hydraulics or water table
  - **Treatment of Inorganics (e.g., cadmium, chromium)**
  - **Well replacement, generally, limited to re-injection well**
  - **Well replacement cheaper**
  - **Less maintenance downtime**
- **GCW**
  - **Uses single well to extract and inject**
  - Manipulation could effect stripping efficiency
  - Flow in = Flow out
  - **Designed not to effect water table**
  - Limited application (e.g., down hole carbon)
  - Well replacement involves entire well
  - More expensive to replace
  - More: down-hole location

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Experience

- **ETR**
  - **Environmental community more experience with ETR**
  - **Applied at far more sites**
  - **Risks, problems, costs & performance characteristics are well known**
  - **Hundreds of good competitive sources for ETR technology**
- **GCW**
  - Environmental community less experience with GCW
  - Applied at far fewer sites
  - Risks, problems, costs and performance less known
  - Only 3 significant national sources of GCW technology known

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Conclusion

- There are good reasons for promoting the use of emerging or innovative technologies
  - When potential to either be more effective, or less costly than conventional technology there is logic in taking risk
- Unfortunately, no widespread potential for GCW to be either more effective or less costly than ETR